

RM 8308

RECEIVED

MAR - 9 1995

**HONDA**  
**AMERICAN HONDA MOTOR CO., INC.**  
955 L'ENFANT PLAZA, S.W. SUITE 5300  
WASHINGTON, D.C. 20024 • (202) 554-1650

FEDERAL COMMUNICATIONS COMMISSION  
OFFICE OF SECRETARY

March 9, 1995

Federal Communications Commission  
Secretary's Office  
1919 M Street, N.W.  
Room 222  
Washington, DC 20554

DOCKET FILE COPY ORIGINAL

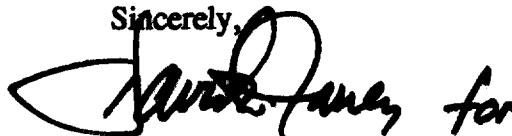
Re: Amendment of Parts 2 and 15 of  
the Commission's Rules to Permit  
Use of Radio Frequencies Above 40 GHz  
for New Radio Applications  
Docket No. 944-124  
RM-83-9

To Whom It May Concern:

On January 30, 1995, Honda submitted comments to the above referenced docket. Included in those comments was a preliminary copy of a Honda study entitled "A STUDY ON TWO-DIMENSIONAL MILLIMETER-WAVE RADAR FOR AUTOMOBILES UNDER THE TIME SHARING MULTIBEAM METHOD". At the time these comments were submitted, the document for this study was incomplete in that it was missing descriptive Figures and Tables. Today, we are submitting a copy of the study which includes those missing Figures and Tables.

We understand that the referenced Docket was closed but hope that consideration can still be given to our submission today. As stated in our January 30 submission, Honda appreciates the opportunity to comment on this important issue.

Sincerely,



Mr. Eiji Amato  
Senior Vice President

Enclosures

No. of Copies rec'd  
List ABCDE

0

RECEIVED

MAR - 9 1995

**A STUDY ON TWO-DIMENSIONAL MILLIMETER-WAVE RADAR FOR  
AUTOMOBILES UNDER THE TIME SHARING MULTIBEAM METHOD**

FEDERAL COMMUNICATIONS COMMISSION  
OFFICE OF SECRETARY

**1. ABSTRACT**

Since sometime in the 1970s, difficulties brought about by automobiles such as increasing accidents, atmospheric pollution, and depletion of energy at the cost of their convenience have been discussed as social problems. Under these circumstances, projects are planned and promoted in advanced road-using countries to solve the problems to be tackled to simultaneously improve safety, reduce congestion, and also to reduce ill effects on the environment by making roads and automobiles intelligent. IVHS in the present report is also ranked as an important project.

This paper deals with the operation support system technology for AVCS etc. It particularly concentrates on radar technology as a necessary component to materialize the advanced ability to recognize and discriminate the external environment, while presenting the techniques using the time sharing multibeam millimeter wave radar developed by us.

**2. INTRODUCTION**

In a mixed-traffic society as we are in, it is necessary not only to ensure the safety of drivers themselves but ensure the safety of mixed traffic. However careful each driver is in mixed traffic, accidents do occur with "a certain probability." This is because advances in mechanical engineering have brought the speed of automobiles some dozen times higher than that of human beings, or beyond the ability of human instincts to avoid danger. Under these circumstances, it is necessary to establish a traffic system that enables traffic elements to avoid collisions autonomously and provide a means for instantaneously transmitting the wish to act to others.

Fig. 1 shows the configuration of the driving support system forming IVHS. As shown here, the driving support system supports and automates all or part of the steps: recognition and decision and operation necessary for the driver's driving operation by detecting the external driving environment with the help of sensors, computers, actuators and communications systems at both vehicle and infrastructure sides. The external environment of driving denotes a wide range of external environments as viewed from the vehicle including such factors as other vehicles nearby, road configuration, condition of road surfaces, weather and drivers. Although the detection of external driving environment is related to the essence of driving, it is the part for which we have relied on human perceptions. Thus, in IVHS, it is also important to realize external sensing techniques that go beyond human perception. One of such external sensing techniques is radar of automobiles. Main possible applications of radar include supplementing the driver's visual information and giving an alarm in the event of danger (rear hit alarm system) and controlling the vehicle with radar information to increase safety (vehicle-to-vehicle distance control system). Table 1 shows the radar systems that are possible at support levels.

**3. RADAR ENGINEERING**

**3-1 Features of Sensors and Current Radio Wave Radars**

For a long time, studies have been made on systems for preventing accidents with alarms in dangerous driving situations, while monitoring the surroundings of the vehicle with external sensors. Table 2 shows typical external sensors and their features.

For laser radar using light, systems with a high-accuracy detecting capacity have been developed through rapid technological innovation, but they have the drawback of being vulnerable to weather.

"Radio-wave radar" developed in the areas of military demand have a high detecting capacity in bad weather (rain, mist, dust, etc.), but its practical use has been delayed by engineering barriers in mass-producing high-frequency devices and compacting antennas. Recently however, trends have been emerging toward using millimeter wave bands for automobile radar in the United States, Europe and in Japan. Europe has already determined a frequency range: 76 - 77 GHz and Japan is planning to use 60 GHz bands. Table 3 shows wave specifications and systems of automobile radar in Europe and Japan.

### 3-2 System Requirements of Radar

To know the likelihood of a car colliding, it is necessary to develop a radar system designed to detect at what locations, in front, beside or at the rear, there are obstacles and how fast and in what direction they are moving as shown in Fig. 2.

Requirements for such radar systems differ with decelerating capacity to stop the vehicles and the limit of vehicle velocity taken into account. Fig. 3 shows the stopping distance of a vehicle running at velocity  $V$  and then braked at decelerating rate  $\alpha$ . The detection distance needed for a vehicle to be stopped without colliding with obstacles must be above the stopping distance here plus the time lag needed for the driver to operate the brakes.

If an obstacle is moving, its velocity must also be detected accurately. The relative velocity can be obtained by differentiating the distance. Here a very high distance accuracy is required.

For a driver to know if his or her car will ultimately collide with an obstacle, information on the lateral location of the obstacle is also needed. Furthermore, automobile radar can operate erroneously due to reflections from guard rails or a failure to detect a target when the vehicle is traveling through a corner. The solution to such difficulties is beam scanning. There are several methods of beam scanning for automobile radar: (1) With continuous mechanical scanning with an antenna beam, discrimination is made between targets and unnecessary reflecting objects from azimuth information and reflected radar signals. (2) A multi-beam system that shifts several antenna beams. (3) A beam-steering system that directs the antenna in the traveling direction when the vehicle is in a corner.

A part from these beam scanning techniques, there is a range cut system that reduces the maximum detection range when the vehicle is in a corner.

## 4. TWO-DIMENSIONAL MILLIMETER-WAVE RADAR UNDER A TIME-SHARING MULTIBEAM METHOD FOR AUTOMOBILES

Considering that the primary purpose of automobile radar is to supplement the human visual sense, we understood that millimeter-wave radar which exhibits excellent properties in unfavorable environments was optimal:

To make the system more intelligent and more reliable than the conventional single-beam radar, a time-sharing multibeam method that shifts beams electrically was selected. To improve azimuthal accuracy, amplitude-angle conversion which is one of the monopolize radar systems was employed. The detection distances required for radar were determined from the stopping distances in Fig. 3. For the necessary distance accuracy, it was decided to employ a technique that calculates relative velocity by differentiating distance data.

Fig. 4 conceptually illustrates the two-dimensional millimeter wave automobile radar under the time-sharing multibeam method.

### 4-1 FFT Calculation of Distance Data and Configuration of Time-sharing Multibeam

The radar system developed by us uses an FM-CW method to measure the distance to the obstacle and calculates the required detection distances by FFT processing. Using FFT processing enables multitargets to be detected, which is difficult under the conventional FM-CW method. Fig. 5 shows calculations for detecting distances.

When trying to realize a two-dimensional radar, an important problem is to compose a multibeam with mounting on vehicles taken into account. Fig. 6 shows an outline of the configuration of a time-sharing multibeam. Fig. 7 shows a time chart for producing a time-sharing multibeam.

### 4-2 Principles of Amplitude-angle Conversion and Two-dimensional Radar Mapping

An amplitude-angle conversion requires at least two beams. The principles are shown in Fig. 8. Fig. 8 (a) shows two beams detecting targets. Suppose that input power  $A$  is detected at CH1 and input power  $B$  at CH2, as shown in Fig. 8 (b). Then calculate the difference  $A - B$  and the sum  $A + B$  and obtain the ratio  $(A - B)/(A + B)$ . From this ratio, the angle between the center line of each beam and the target concerned can be obtained. Fig. 8 (C) shows the relation between ratio  $(A - B)/(A + B)$  and angle  $\theta$  between the target and the beam center line.

Preparing a two-dimensional radar map consisting of polar coordinates as shown in Fig. 9 requires a time-sharing multichannel radar system consisting of several channels of the FM-CW radar, described earlier, arrayed in the azimuthal direction.

First, the beat signals that are the output signals of the channels are input into the FFT frequency analysis to calculate spectrum data. The spectrum data of the frequency components corresponds to the distance coordinates, and is arrayed from low frequency at the origin of the coordinates to high. The channel numbers correspond to the azimuthal coordinates and the spectrum data of the channels are arrayed in the order of the azimuthal direction in scanning.

To increase the calculating accuracy of the azimuthal coordinates for the frequency spectra arrayed on the polar coordinates, the amplitude-angle conversion principles explained in Fig. 8 were employed. This processing enables an azimuthal resolution above the number of the channels to be obtained for the azimuthal coordinates of objects.

Using the spectrum data array obtained by the procedure above, a two-dimensional radar map can be prepared and represented in PPI.

#### 4-3 Performance Evaluation

Distance accuracy and lateral accuracy necessary for two-dimensional radar were measured. The results are as follows:

A corner reflector having a comparable reflection cross-section with a smaller car was used as a target and distance accuracy was measured. Fig. 10 shows the results with a detection distance of 100 m. Here, the distance accuracy is within about 50 cm, showing that it is a very high-accuracy radar system.

It was already known that distance accuracy under an FM-CW system is determined by the properties of the FM oscillator. We attained the high distance accuracy shown in the figure using a high-performance FM oscillator. This also showed that the relative velocity could be calculated satisfactorily by differentiating distance accuracy.

The corner reflector mentioned above was placed at a distance of 100 m and then laterally moved at 1 m intervals within a range of  $\pm 5$  m. The results of measurements are shown in Fig. 11. Evidently, the lateral accuracy is within about 1 m. This also shows that the system is also a high-accuracy model of two-dimensional radar.

All this proved that the "time-sharing multibeam radar" we developed had a higher accuracy than conventional millimeter wave radar.

#### 5. CONCLUSION

The current automobile traffic system, has such poor information communication between its elements that safety there relies on the sensory functions of drivers. Under such circumstances, it is desirable to carry out IVHS projects promptly and develop them further. It is observed in particular that supplementing the sensory functions of drivers and making a practical "automobile radar" beyond human sensory perception are essential to IVHS projects. As IVHS projects proceed, the "millimeter wave radar" presented here is expected to be satisfactorily effective. To promote the spread of this millimeter wave radar, its engineering must be changed from conventional concentrated applications in military areas to the private sector. It also seems necessary to actively utilize the MMIC technology recently studied enthusiastically.

#### Reference

1. K. Hashimoto, et al., "An Image Processing Architecture and a Motion Control Method for an Autonomous Vehicle," Intelligent Vehicles '92 Symposium, 1992, Detroit.
2. K. Hayafune, "Categorization of the Driver Support Systems," No. 9406, 1994, 2.
3. Furukawa, "Future Trends of Automobile Safety Engineering," SAE/IEEE Convergency, 92
4. S. Takaba, "Tasks and Future in Driving Support Systems," No. 9406, 1994, 2.
5. Y. Eto, et al., "Development of Radar for Automotive Use and Application for Preceding Car Following System," Nissan Technical Report.
6. Y. Fujita, "Microwave Radar Sensor for Automobile," Development of "Smart" Vehicles, Current Trends and Problems, 1991.

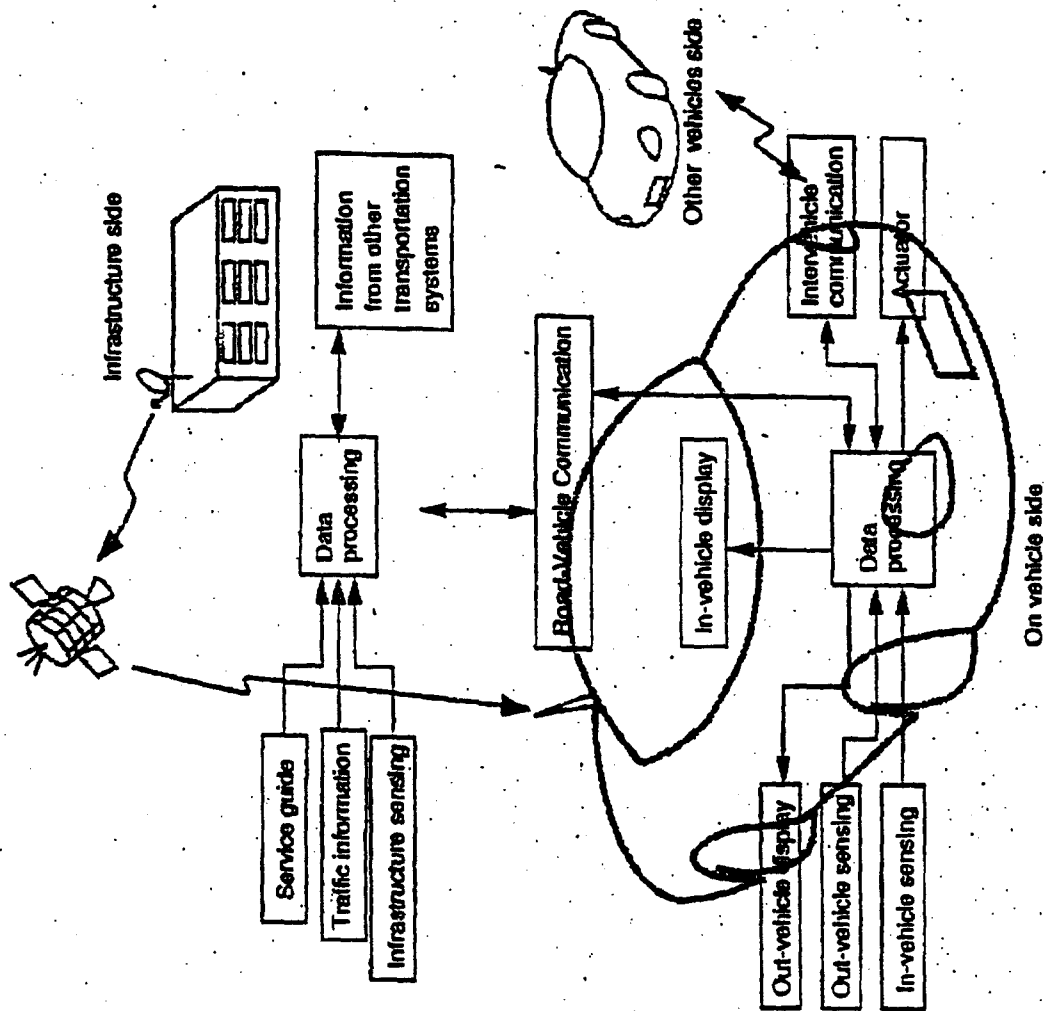
7. M. Iguchi, "Vehicle, Road and Traffic Intelligence Systems Update," No. 9406, 1994.
8. A. I. Lenoy, "Monopulse Radar," ARTECH HOUSE, 1986.
9. M. Skolnik, "Introduction to Radar Systems," McGraw-Hill, 1962.
10. Millimeter Wave News, No. 3, 1992.

# **A Study on Two-dimensional Millimeter-Wave Radar for Automobiles under the Time Sharing Multibeam Method**

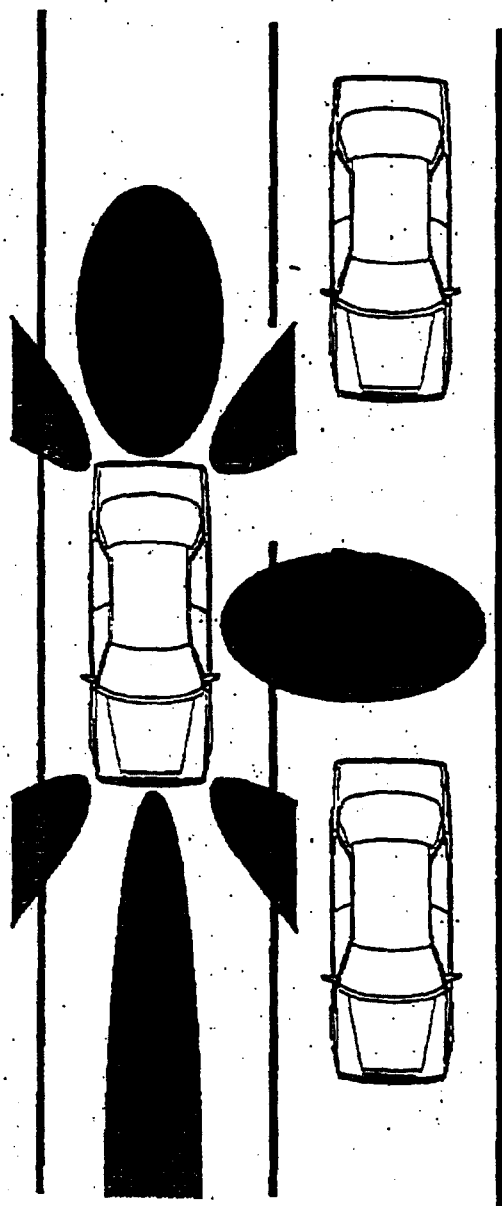
**Satoru Komatsu   Joe Kojima   Hideaki Ono   Kauhisa Satoh**

---

**(Honda R&D Co., Ltd.   Wako Research Center)**

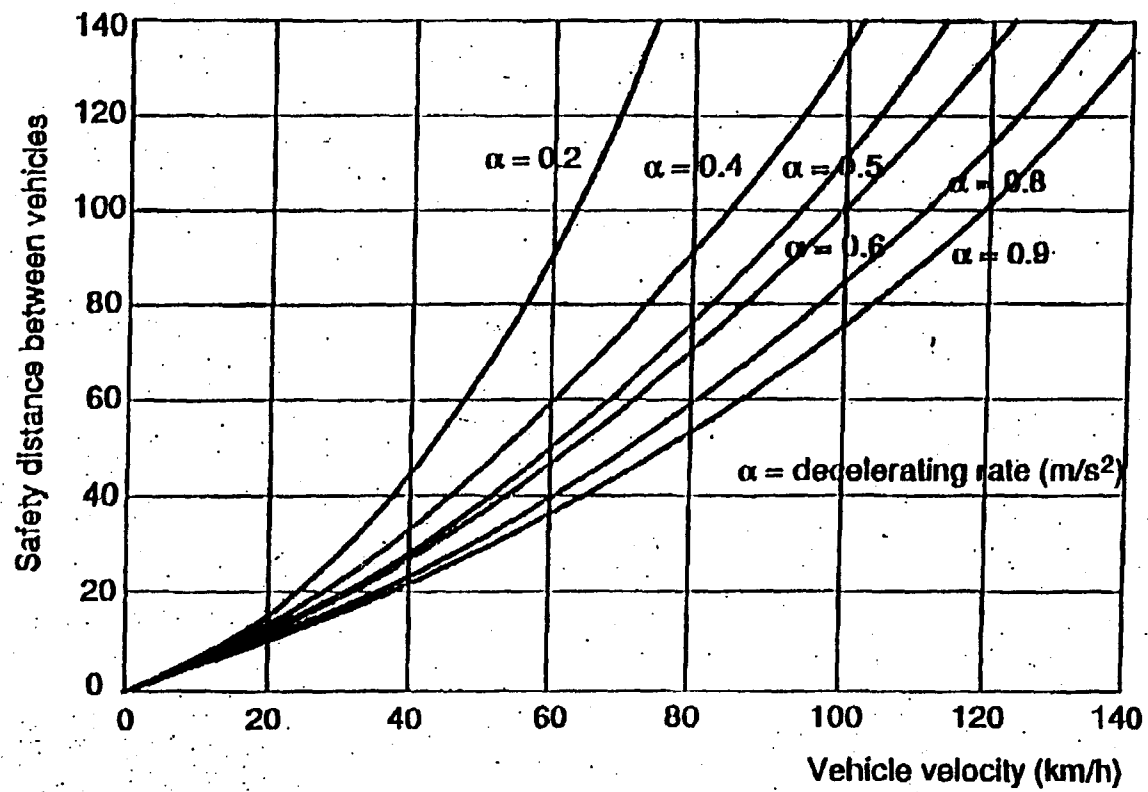


**Fig. 1**

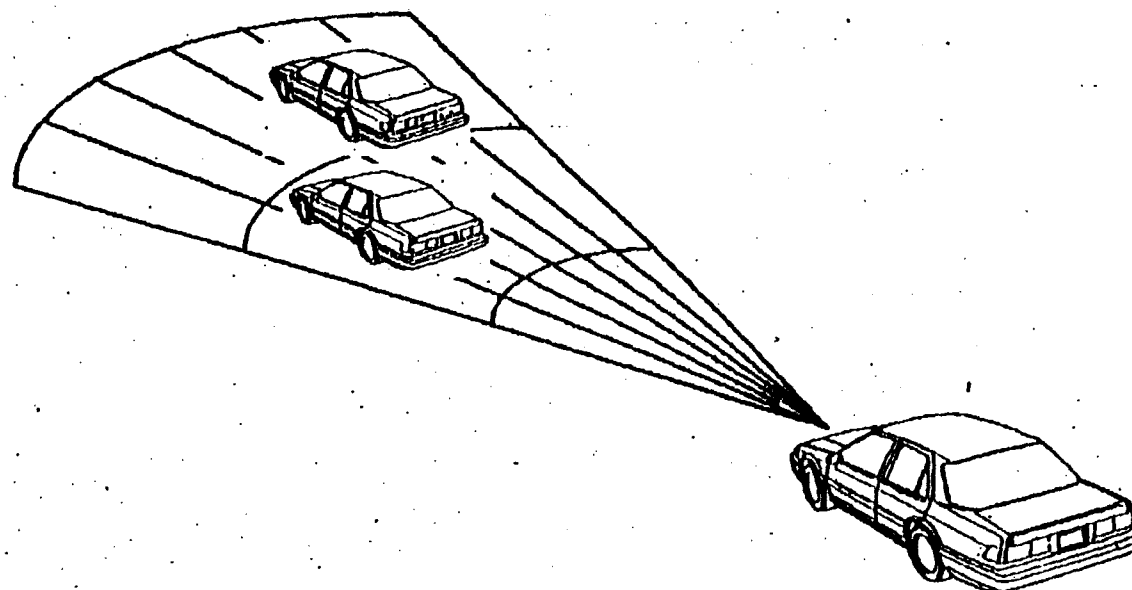


**Fig. 2 Detection areas necessary for driving support system**





**Fig. 3 Vehicle velocity and safety distance between vehicles**



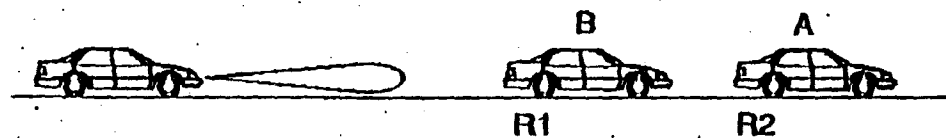
Realization of millimeter wave  
automobile radar system



Unique system

- Time-sharing multibeam system
- Amplitude-angle conversion algorithm
- FFT processing

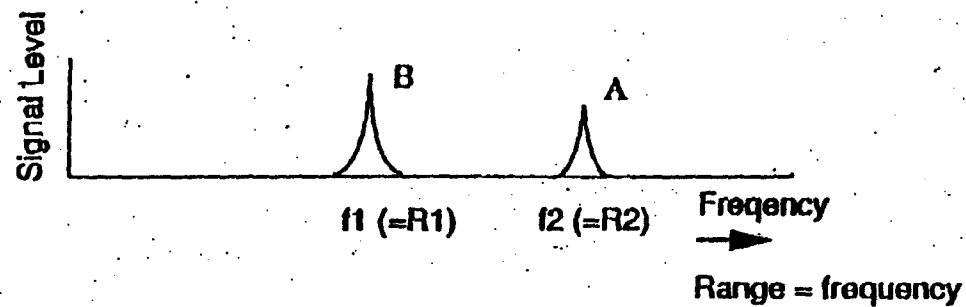
**Fig. 4 Two-dimensional millimeter wave automobile radar  
under time-sharing multibeam system**



(a) Vehicle

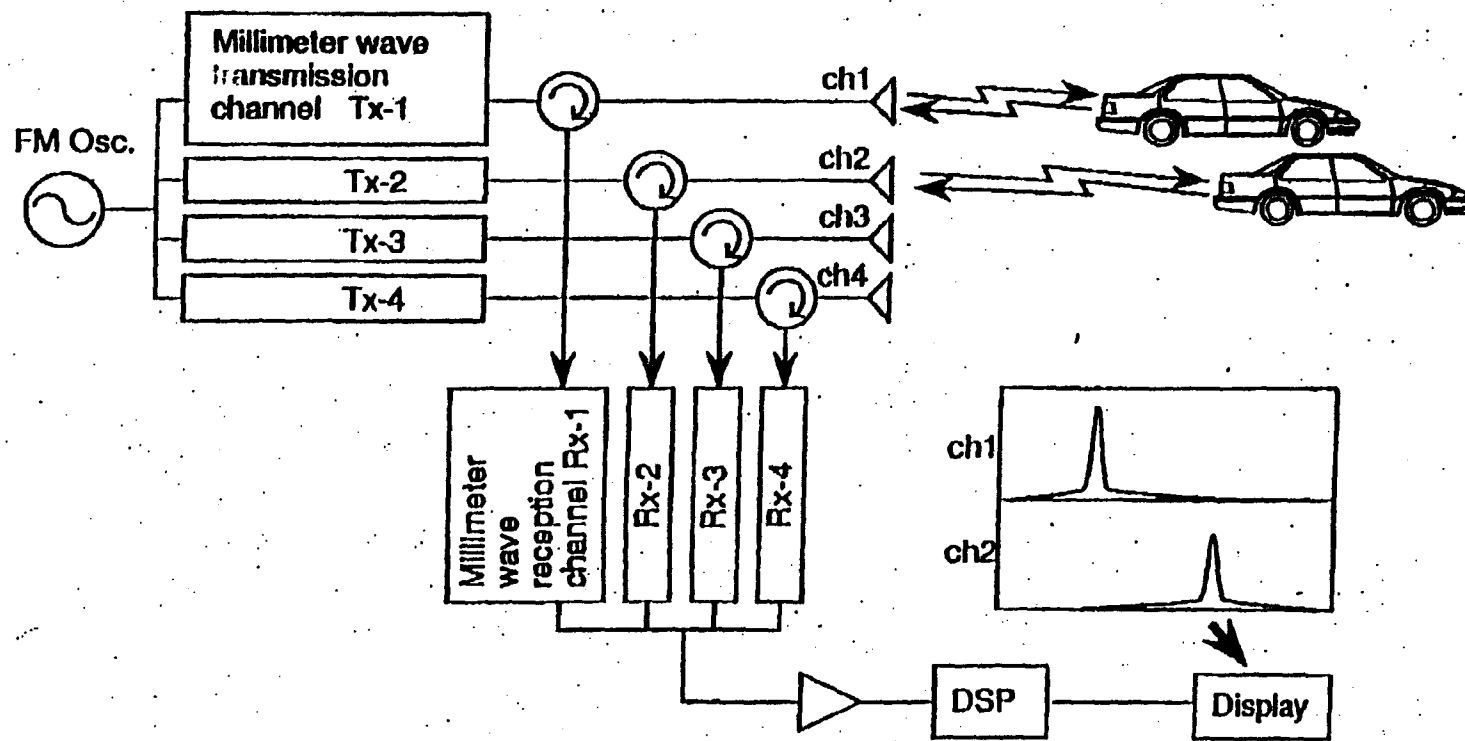


(b) Video signal

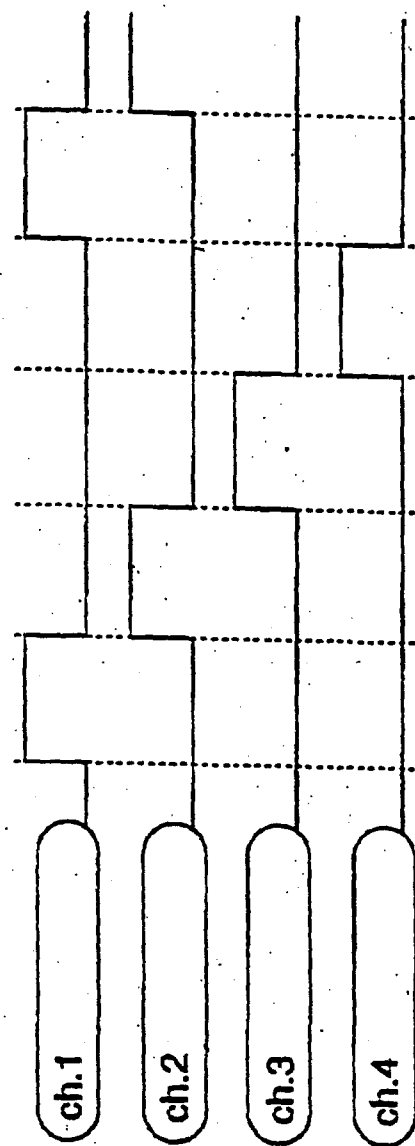


(c) Spectrum analysis by FFT

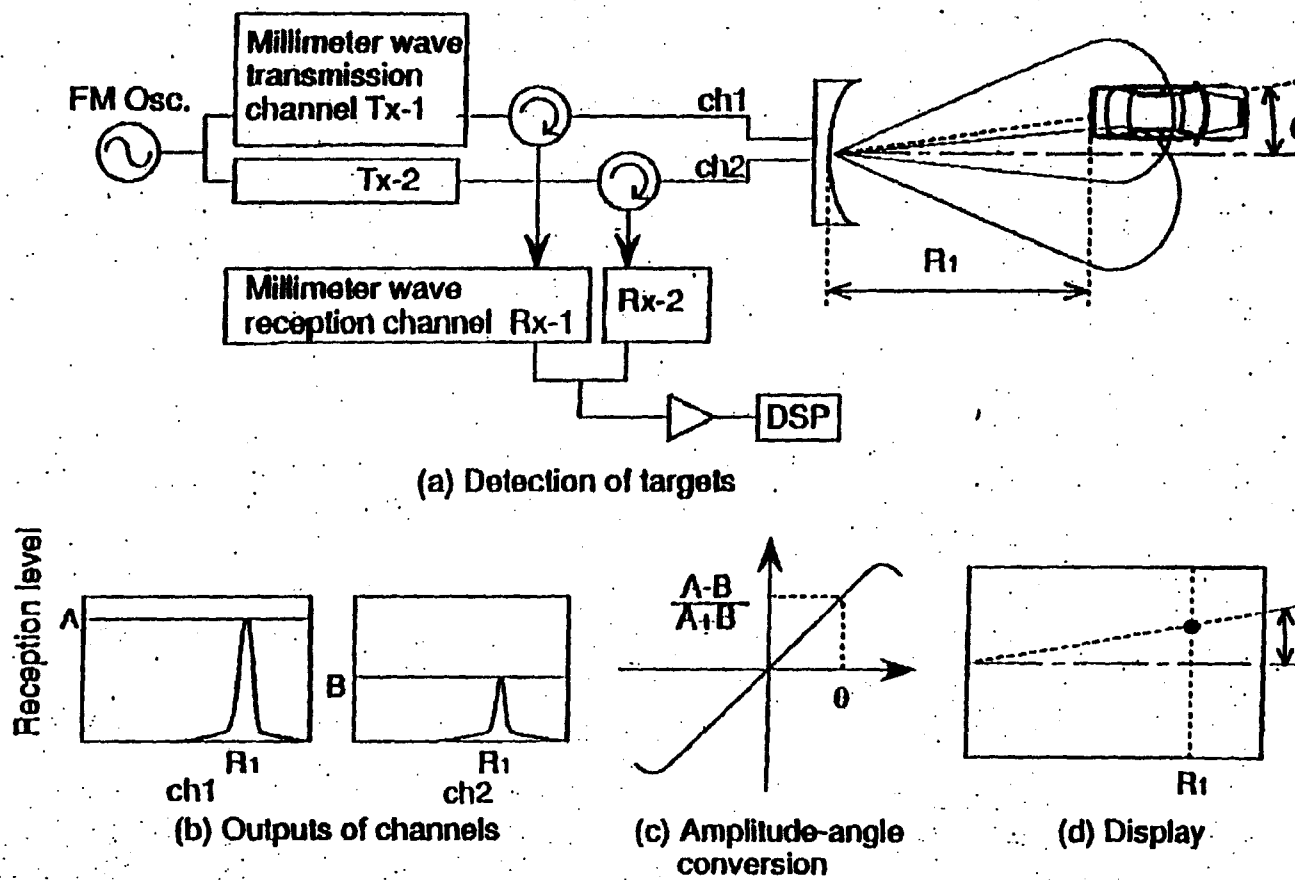
**Fig. 5 Principles of multitarget detection by FFT processing**



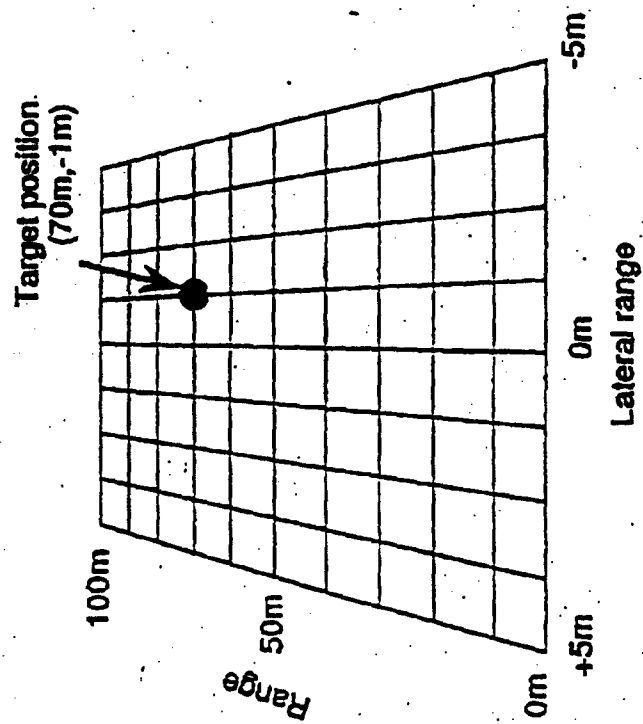
**Fig. 6 Configuration of time-sharing multibeam millimeter wave radar system**



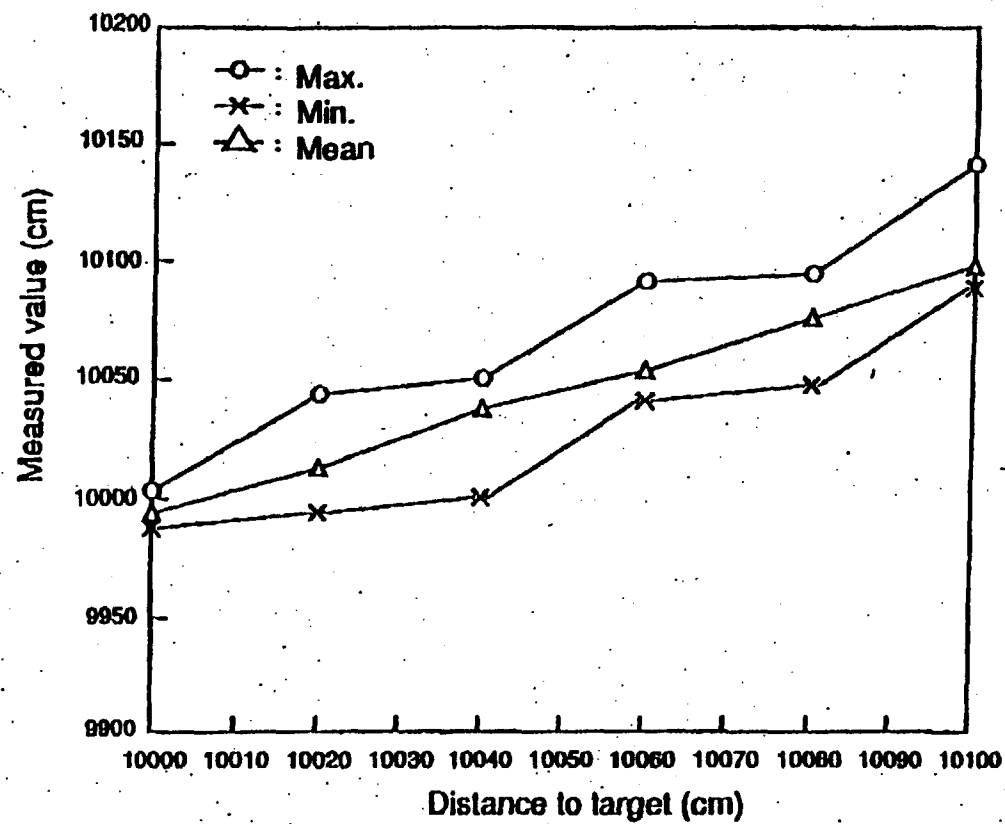
**Fig. 7 A time chart for producing a time-sharing multibeam**



**Fig. 8 Principles of amplitude-angle conversion**

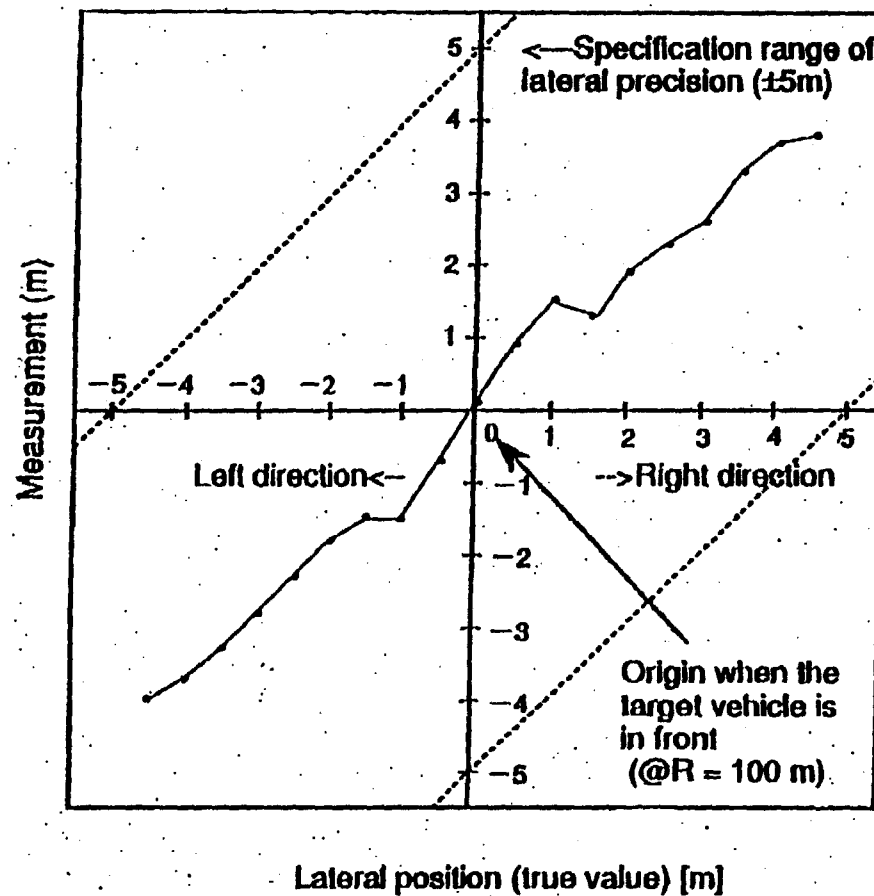


**Fig. 9 Two-dimensional PPI display**



**Fig. 10 Results of measurements of distance accuracy**





**Fig. 11 Measured results of lateral precision (R = 100 m)**

**Table 1 Classification by support levels**

Support level	Advice system	Alarm system	Partial automatic	Partial/full automatic
Systems	Advice on load surfaces	Alarm for obstacles	Intelligent auto-cruise	Automatic run on exclusive lane
	Monitor for surroundings	Alarm for "out of lane"	Lane keeping	Automatic parking
		Alarm for blind corner obstacle	Speed limiting before entering curve	Natural following in congestion
			Auto-braking	Convoy run

**Table 2 Kinds and features of external sensors**

Sensor	Features
Ultrasonic sensors	Commercial short-range alarms Compact, low-priced, vulnerable to environment.
Laser radar	Commercial long-range obstacle detection, near infrared laser. High-accuracy, high-function.
Radio radar	Long-range obstacle detection, microwave or millimeter wave. High-accuracy, all-weather.
Image sensors	Two dimensional visible/infrared light. Discriminates objects and measures distances. Requires image processing techniques.

**Table 3 Specifications of automobile radar systems  
in Europe and Japan**

	Europe	Japan
Frequency	76-77GHz	59-64GHz band (59-60GHz testing practicalization band)
Bandwidth	FM-CW 100MHz Pulse 500MHz	Assigned frequency band (Frequency deviation + occupied bandwidth)
Output	40-100mW	10mW or less
Modulation	(1) FM-CW (2) Pulse	(1) FM-CW (2) Pulse (3) Two-frequency CW (4) SS
License	1990 granted	1995, report scheduled